Rapid Disintegration of Bald Patches in a Major Solar Eruption

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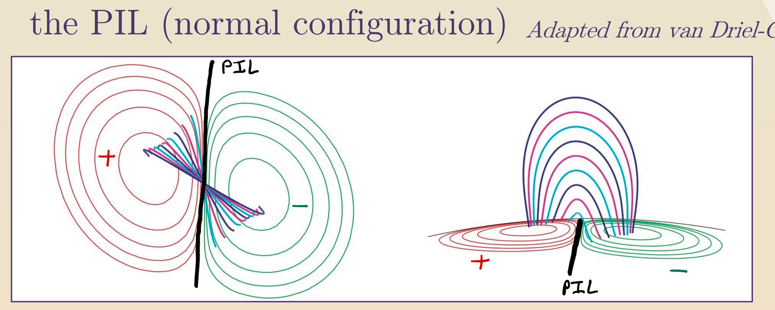
ABSTRACT

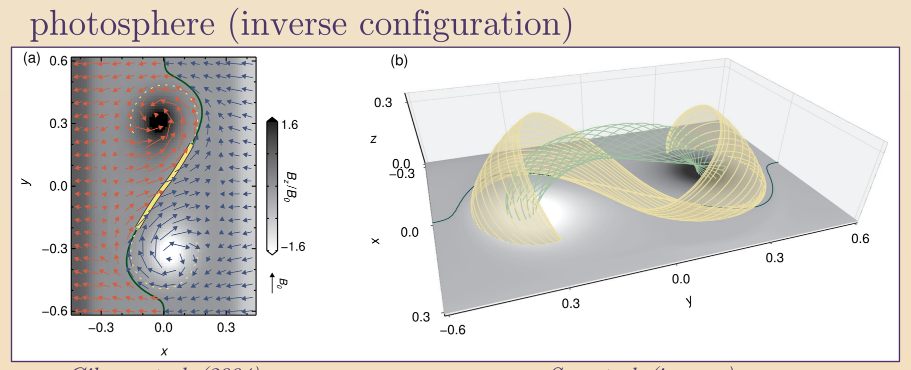
- A bald patch (BP) is a magnetic topological feature where U-shaped field lines turn tangent to, and graze, the photosphere
- Field lines threading the BP trace a separatrix surface where reconnection preferentially occurs
- Here we study the evolution of numerous BPs in active region (AR) 12673 during the most intense flare of solar cycle 24
- Multiple BPs formed along the polarity inversion line (PIL) prior to the flare with the central BP largely "disintegrating" within 35 minutes while the southern BP survived
- Disintegration manifested as a 9° rotation of the magnetic shear angle, the perpendicular component of the horizontal field (with respect to the PIL) changed sign, and the parallel component exhibited a step-wise, permanent increase of 1 kG
- The observations suggest that magnetic reconnection during a major eruption may involve entire BP separatrices, leading to a change of magnetic topology from BPs to sheared arcades

BALD PATCHES

- **B** vector normally points from positive to negative polarity in a typical bipolar solar AR resulting in Ω-shaped field lines straddling the PIL (normal configuration) *Adapted from van Driel-Gesztelyi & Green (2015)*



- Sometimes **B** vectors point from negative to positive polarity resulting in U-shaped field lines that dip down and tangentially touch the photosphere (inverse configuration)

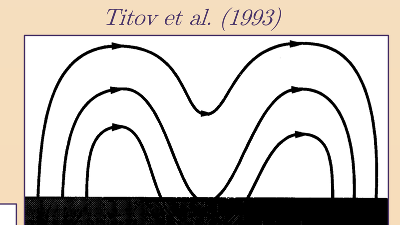


Gibson et al. (2004) *Sun et al. (in prep)*

- This magnetic configuration, known as a BP, appears when the photospheric **B** vector satisfies the following BP criterion (Titov et al. 1993):

$$(B_h \cdot \nabla_h B_z)|_{B_z=0} > 0$$

Titov et al. (1993)



- Where:
  - B_h = horizontal field
  - B_z = vertical field
  - B_z = 0 defines the PIL
  - $\nabla_h B_z$ = gradient vector pointing perpendicular to the PIL from negative to positive polarity

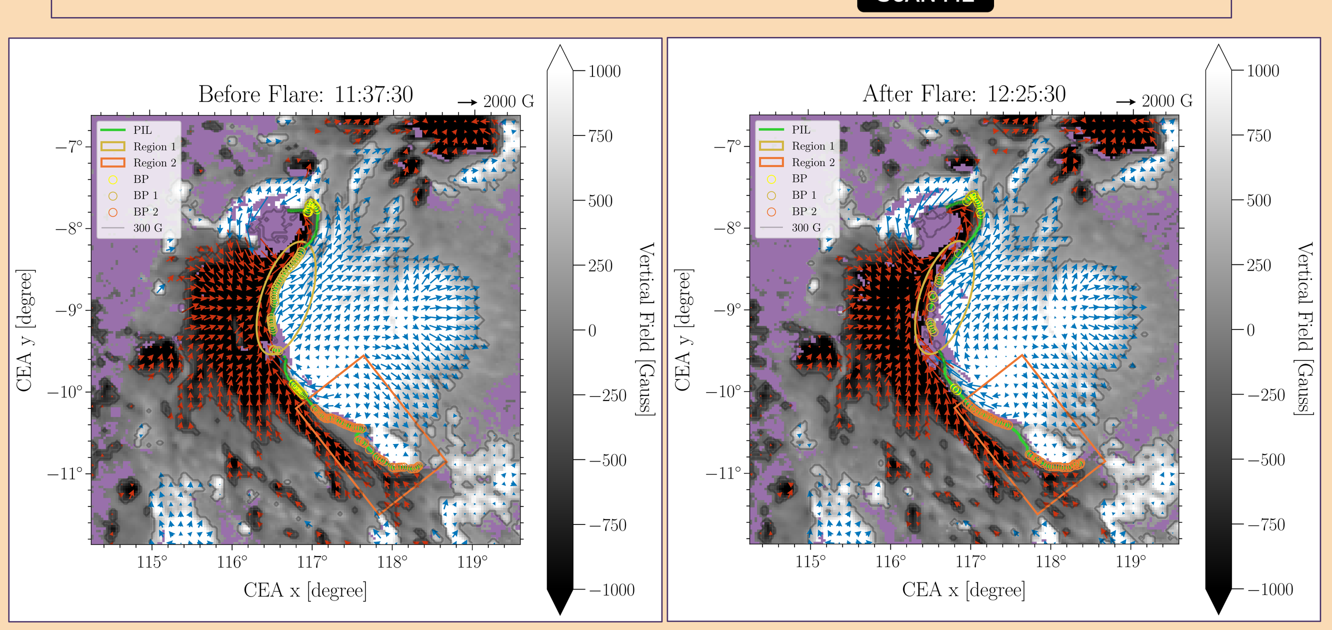
Bald Patch (BP)

AR 12673

- *GOES* X9.3 flare on 09/06/2017 starts, peaks, and ends 11:53 UT, 12:02 UT, and 12:10 UT, respectively
- BP disintegration observed in Region 1
- BP survival seen in Region 2

SCAN ME

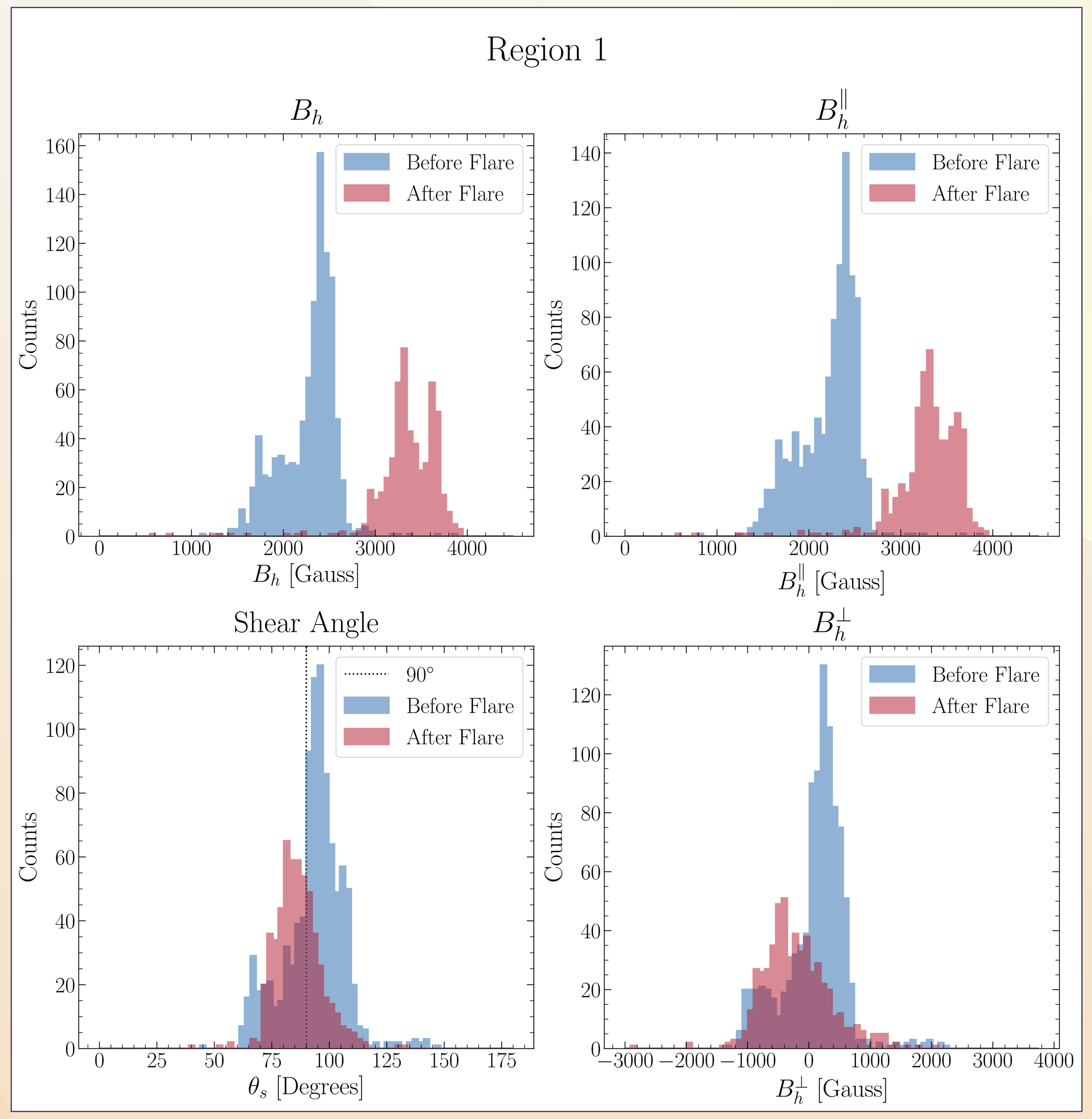
Animation of this figure available



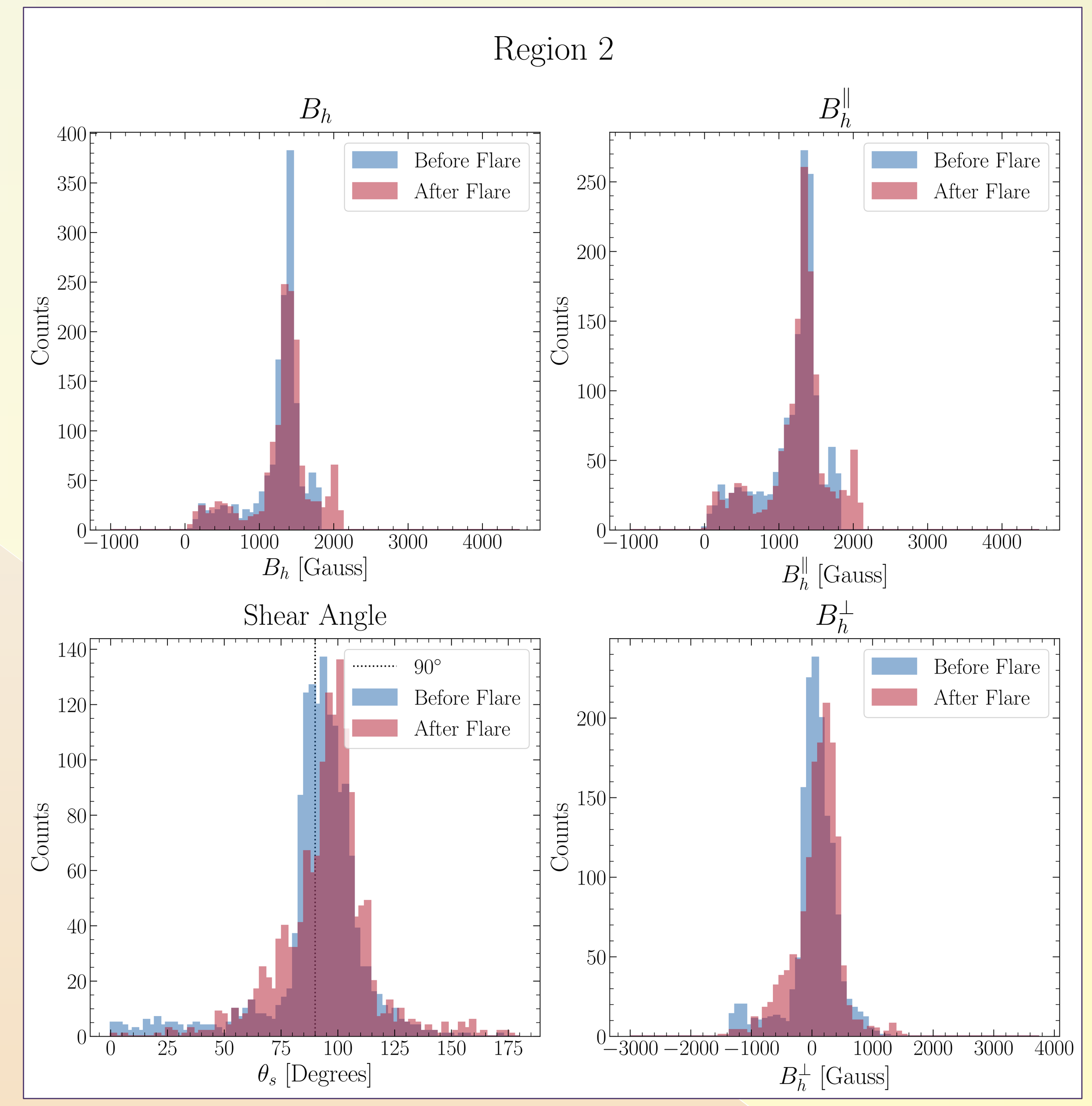
DATA, METHODS, AND ANALYSIS OF REGION 1 AND REGION 2

- We analyze 88 frames of *Solar Dynamics Observatory* (*SDO*) Helioseismic and Magnetic Imager (HMI) 90 s cadence vector magnetograms
- Data spans roughly two hours centered around the flare peak
- We use the zero vertical field contour, $B_z = 0$ G, to identify PIL pixels
- Distributions are for 17 combined time steps before (blue, 11:27-11:51 UT) and after (red, 12:12-12:36 UT) the flare at the PIL pixels in Region 1 and Region 2
- Temporal profiles show median values along the PIL for all 88 frames in Region 1 and Region 2
- Statistical uncertainty for each time series measurement estimated using Monte-Carlo methods
- Flare ribbon loci derived from *SDO's* Atmospheric Imaging Assembly (AIA)1600 Å images
- We calculate the following variables of interest for the PIL pixels:
  - B_h = horizontal field strength
  - $B_h^{\parallel}$ = parallel component of B_h with respect to the PIL
  - $B_h^{\perp}$ = perpendicular component of B_h with respect to the PIL
  - θ_s = magnetic shear angle where:
    - θ_s = 0 when **B** is perpendicular to the PIL and points from the positive to negative polarity
    - BPs have $\theta_s > 90°$
    - Sheared arcades have $0° < \theta_s < 90°$

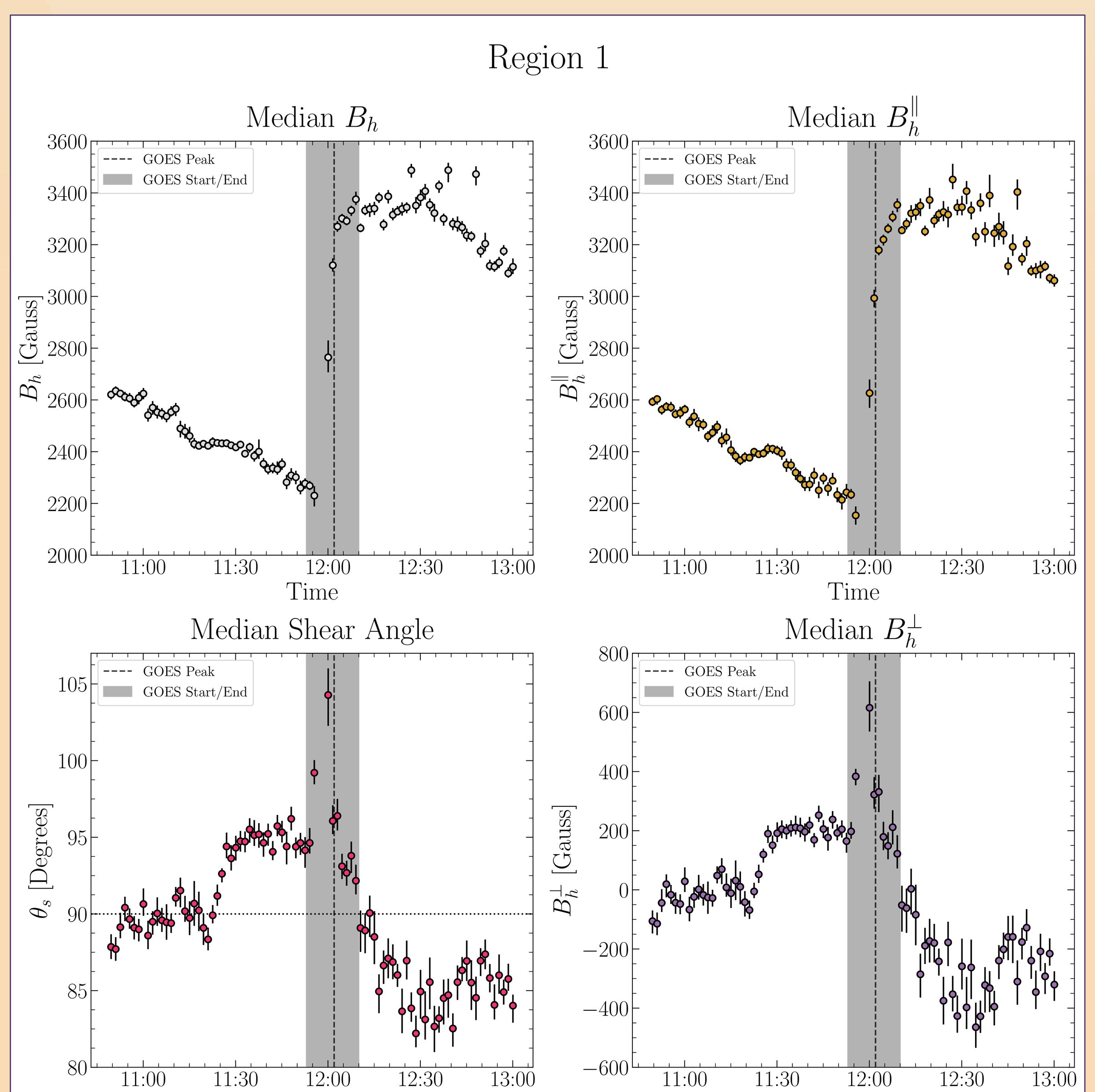
REGION 1 DISTRIBUTION



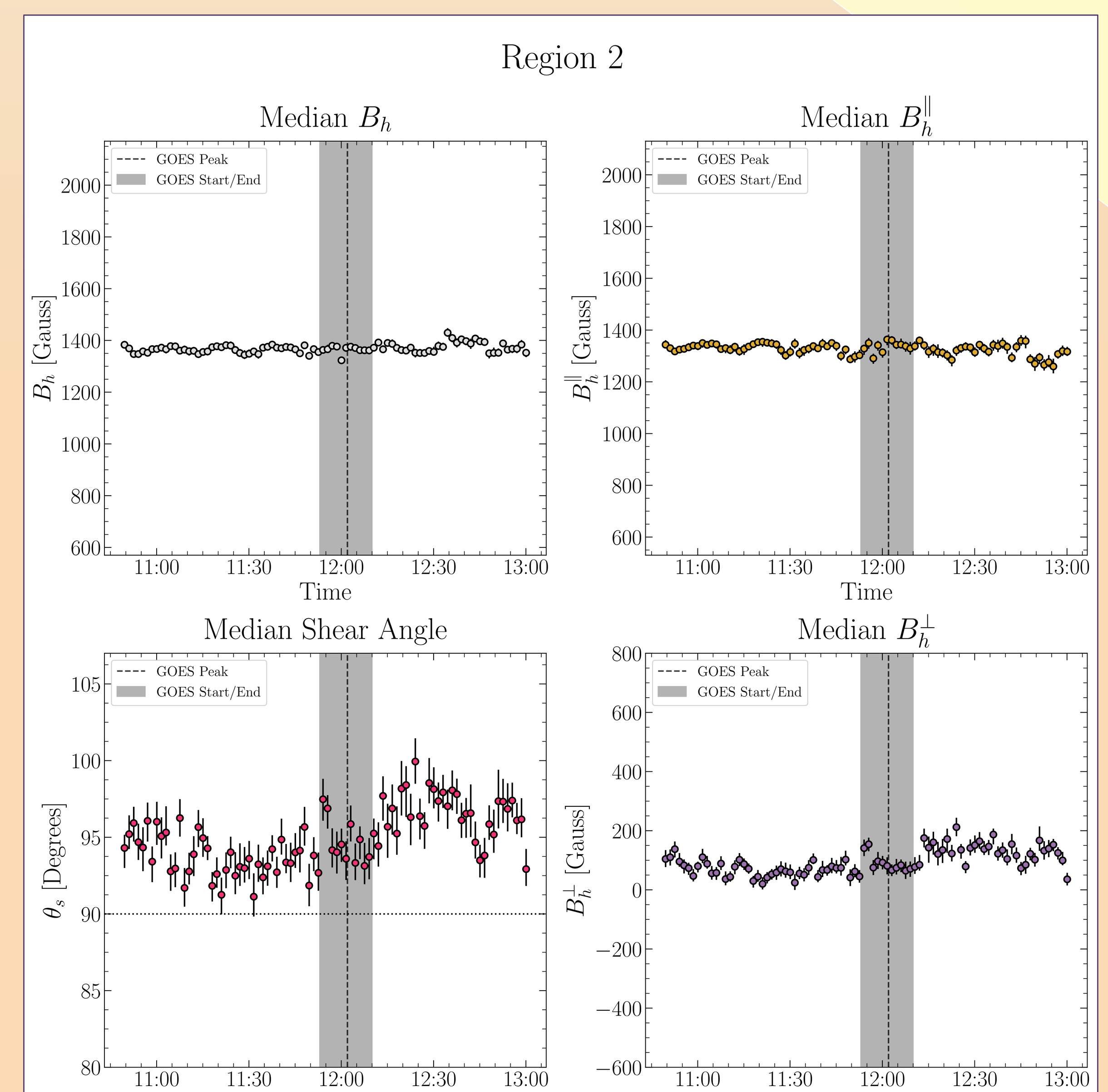
REGION 2 DISTRIBUTION



REGION 1 TIME SERIES

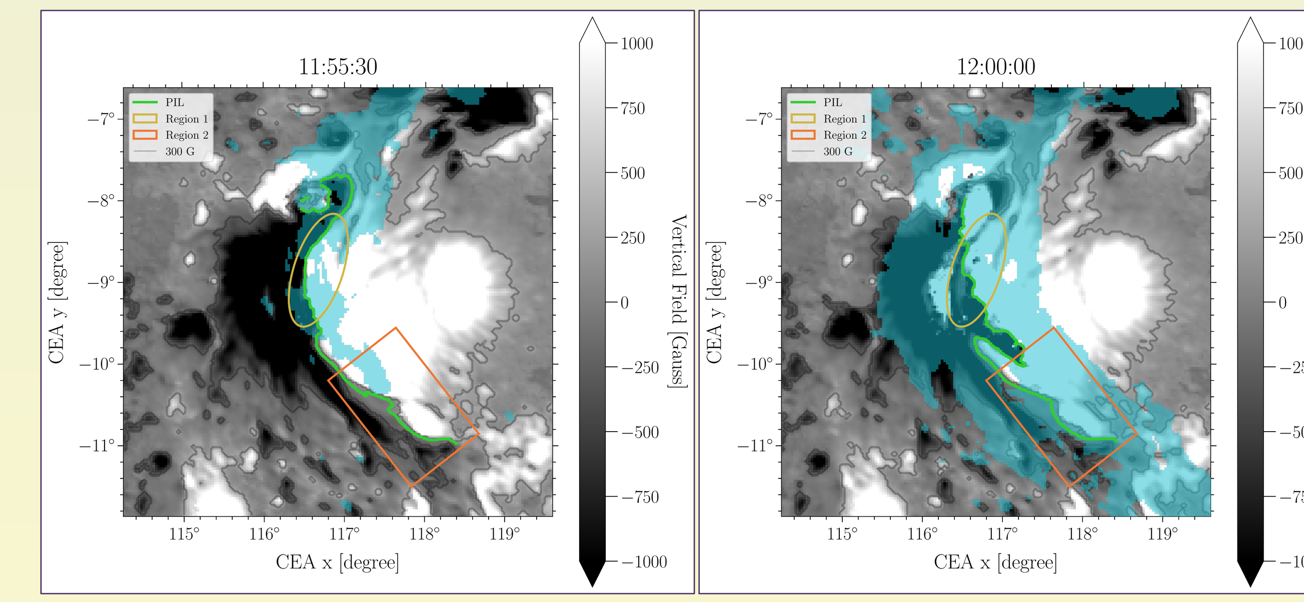


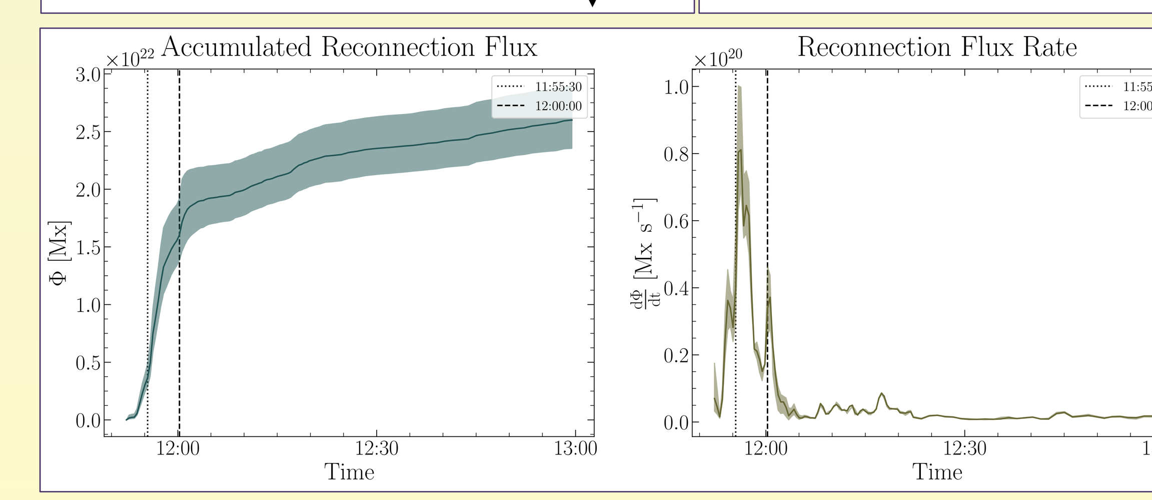
REGION 2 TIME SERIES



FLARE RIBBONS

- Flare ribbons (teal) appear close to the northern portion of the PIL, including Region 1, during flare onset and evolve outward eventually covering Region 2 during the peak of the flare
- Early, more intense reconnection when the reconnection flux rate $d\Phi/dt$ was near its maximum (8.11×10^{19} Mx s^{-1}), likely occurred at lower altitudes above Region 1 and may have involved the entire BP separatrix, leading to rapid BP disintegration
- Region 2 was involved later when $d\Phi/dt$ was reduced (3.72×10^{19} Mx s^{-1}) and reconnection proceeded to higher altitudes suggesting the BP separatrix there was less involved, and the BPs survived





Animation of flare ribbon evolution available

SCAN ME

CONCLUSIONS

- BP disintegration is observationally coupled with:
  - A sharp and permanent increase of roughly 1 kG in $B_h^{\parallel}$
  - $B_h^{\perp}$ changes sign from positive to negative
  - θ_s dips below 90°
- Flare ribbons suggest intense reconnection proceeding to very low altitudes at Region 1 and involving the entire BP separatrix there
- Simulations show a low-lying magnetic flux rope (MFR) forming above the PIL of AR 12673 a couple days before eruption (Jiang et al. 2018; Liu et al. 2019)
  - During the eruption, the MFR accelerates and expands outwards, lifting the lowest dipped U-shaped field lines, converting the stretched BP separatrix to sheared arcades, and annihilating the BPs (Fan & Gibson 2007)

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